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PROVISIONAL APPLICATION COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION under 37 CFR 1.53(b)(2)

Docket Number	50412-1	Type a Plus Sign (+) inside this Box ->	+

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TITLE OF THE INVENTION (280 CHARACTERS MAX.)

A Time/Motion Compensation Engine for HMDs

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ENCLOSED APPLICATION PARTS *(Check all that Apply)*

X	*Specification*	*Number of pages*	10			*Small Entity Statement*	
X	*Drawing(s)*	*Number of Sheets*				*Other (specify)*	

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The invention was made by an agency of the United States Government or under contract with an agency of the United States Government. X No

Date: Sept. 22/99

Respectfully submitted,

Juliusz Szereszewski
Patent Agent for Applicant
Regn No. 32,672

Enclosurers
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_____ Additional inventors are being named a separately numbered sheets attached hereto.

PROVISIONAL APPLICATION FILING ONLY

A Time/Motion Compensation Engine for HMDs

The following discussion describes the Time/Motion Compensation Engine. This is a means of providing a user with a stable frame of visual reference for aspects of a visual telepresence loop which would otherwise induce nausea.

1. Introduction

A typical application using the Time/Motion Compensation Engine (T/MCE) is depicted in Figure 1 below. It consists of an operator using a head tracker to remotely control a camera as a slave. The video returned from the camera is presented to the operator in a Head Mounted Display (HMD). If the control and feedback paths are delayed (eg. 0.1 sec to 5 sec), presentation of the video directly in the HMD would induce nausea in the operator, due to the lack of co-ordination between head motion and visual cues.

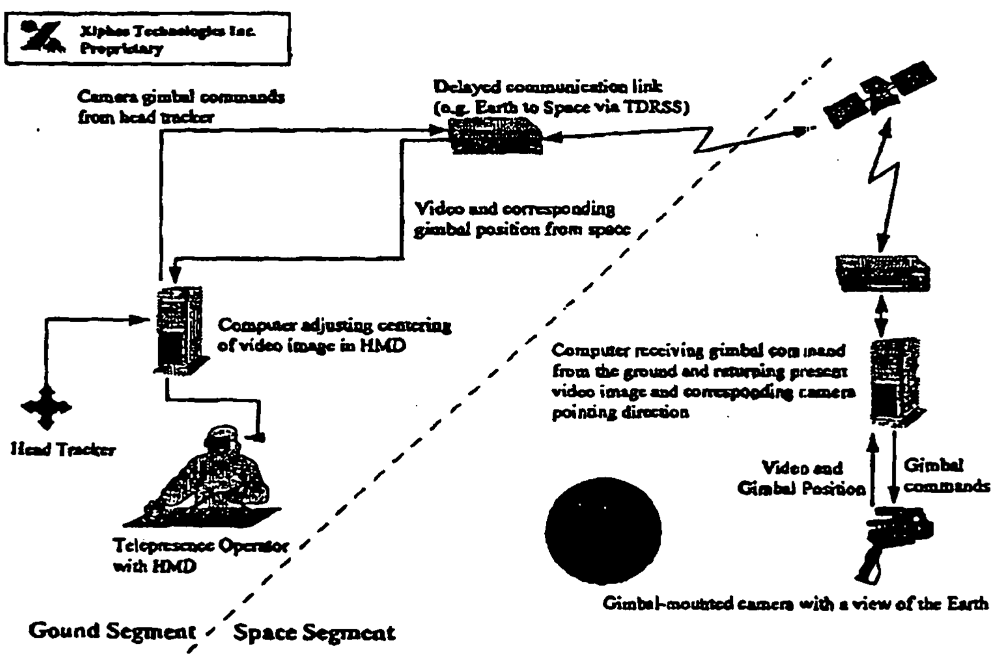


Figure 1. Delay-Compensated HMD Video System

As depicted in Figure 1, a computer has been inserted in the path of the video feedback from the camera. This computer can move the video image relative to the operator's HMD field of view. This is done in either software or hardware, and can be done at the same rates as the operator's head motion. The following discussion will describe how this ability can be used to provide the operator with a stable frame of visual reference for three aspects of telepresence which are capable of inducing nausea:

1. Head motion without corresponding camera motion,
2. Camera motion without corresponding head motion, and
3. Communication delays between head motion and the resultant corresponding camera motion.

2. Field of View

In the Figure 2, we see the camera's view of the Earth. The field of view (FOV) of the HMD is depicted by the dashed lines. This is the area seen by the operator in his display. The gray area around this depicts the range over which the computer can re-locate the video image. This gray area is, in fact, 3-dimensional and describes the interior of a sphere. For this discussion, we will assume it is flat and head motions are small.

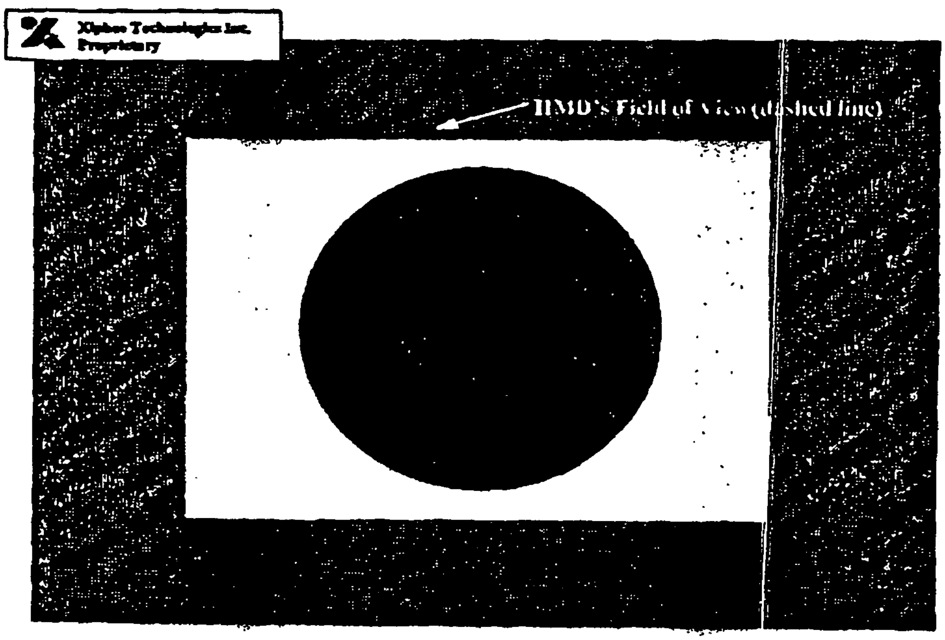


Figure 2. Initial Camera View

Thus, the computer can move the image so that it is not co-located with the part of the region displayed on the HMD. If the image is removed from the HMD's field of view, it is replaced by a neutral gray tone. This is depicted in Figure 3 below, where the video image has been moved up and to the right.

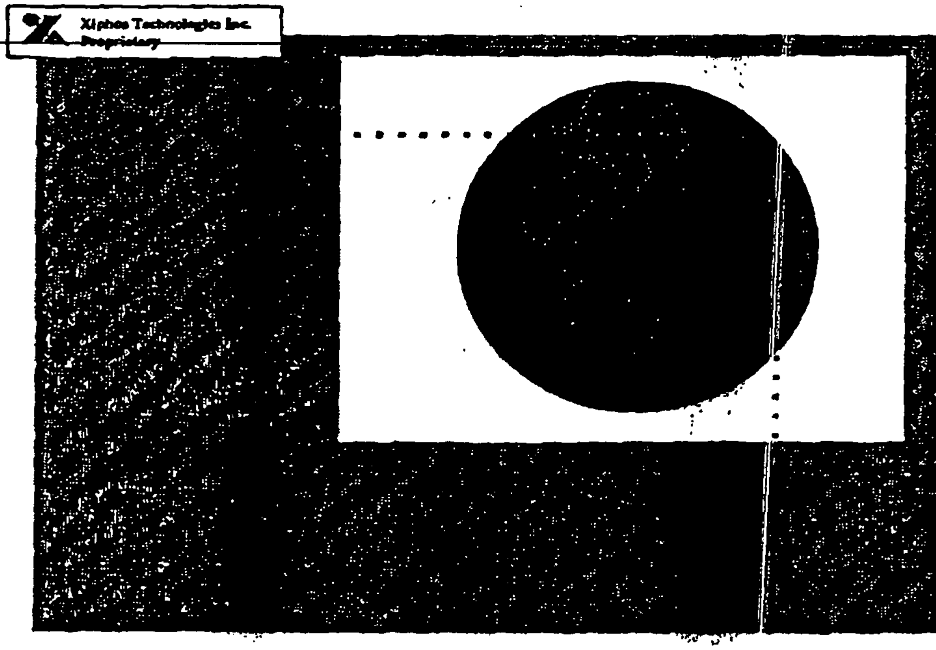


Figure 3. Video Image Displaced Relative to HMD Field of View

3. Time/Motion Compensation

The method of compensating for time and motion incongruities in the HMD will be presented in three parts:

1. Head motion without corresponding camera motion,
2. Camera motion without corresponding head motion, and
3. Communication delays between head motion and the resultant corresponding camera motion.

The third of these is actually a result of the first two, and does not require added functionality.

3.1. Compensation for Head Motion

To provide a stable frame of visual reference for the operator, it is first necessary to permit free head movement, without depending on the remote camera to provide an instantaneous response. The worst case for this is having the camera fixed, and the operator moving his head. In this scenario, the image must remain fixed in one location of 3-D space, as perceived by the operator. That is, in turning his head, he would look away from the image as if looking away from a window frame in front of him.

The stable frame of reference is provided by having the contents of the window remain fixed in 3-D space.

The image already shown in Figure 3 is the one that would result from the following example case. Starting from Figure 2, the camera is locked in a fixed direction and the operator moves his head down and to the left. The computer reading the head tracker would slide the image up and to the right in real time. This provides the operator with a sensation that he is looking at the Earth through a window in front of him. He has looked down and to the left, thus the scene in the window is the same, but the window frame is now located above and to his right. Because the frame and its contents have moved appropriately for his head motion, there is no nausea.

The displacement of the window is continuous and smooth; the required speed of displacing the window frame is the same as that of a generating a virtual environment for a VR HMD user. However, no graphics are being generated. Since the only operation of the computer is moving a video window relative to its display centre, this can be done very fast in hardware or software. Processing speeds are thus reasonable.

If large head motions (or a narrow-angle video image are anticipated), it may be desirable to add horizontal and vertical pinstripe reference lines to the gray area to help the operator maintain orientation if he looks so far from the window frame that no part of the image is visible.

3.2. Compensation for Camera Motion

To provide a stable frame of visual reference for the operator, it is also necessary to permit free camera movement, without having input the corresponding head-motion command first. In itself, this capability is applicable to mobile camera platforms, where the platform may be subject to unanticipated motion. In cases where the camera is stabilized on a gimbal or where the operator is on a motion base, this capability can provide a very high frequency response which would otherwise incur cost, power and weight penalties in a mechanical system. This high frequency response may be complementary to the mechanical response of the gimbal or motion base.

The baseline scenario is one where the operator's head is fixed, and the camera is moving independently. In this scenario, the *contents* of the scene must remain fixed in one location of 3-D space, as perceived by the operator. The window frame, however, must move with the camera. That is, as the camera moves, the operator will perceive the field of view moving about, as if the window *frame* in front of him were moving. The elements of images seen through the frame (such as the Earth) would remain fixed in 3-D space.

The stable frame of reference is provided, once again, by having the contents of the window remain fixed in 3-D space, as perceived by the operator.

The next example describes the algorithm's ability to move the window frame according to the camera's pointing angle. Here, the operator's head is fixed, and he is looking to the left and below the Earth through the remote camera. This is shown in Figure 4 below.

Now, (for whatever reason) the camera pans up and to the right *without the operator moving his head.* The video data being downlinked is accompanied by data describing the instantaneous pointing direction of the gimbal mount, and the motion of the platform. The computer reads this data, and moves the image (and window frame) up and to the right according to where the camera is pointing. The resulting presentation to the user is that of Figure 5.

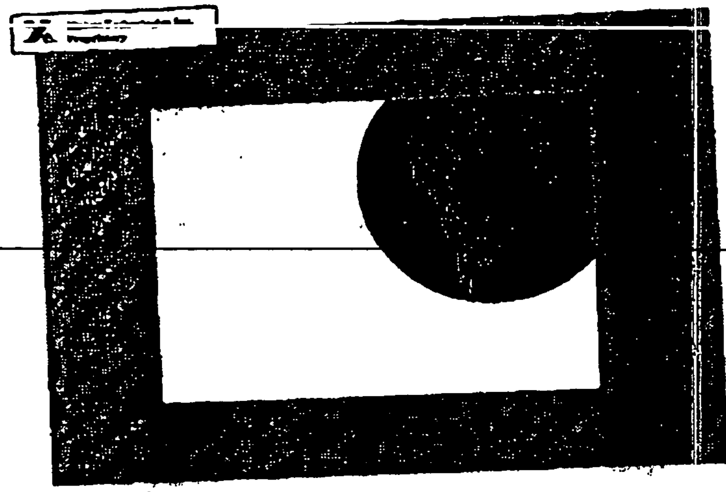


Figure 4. Initial View Below and to the Left

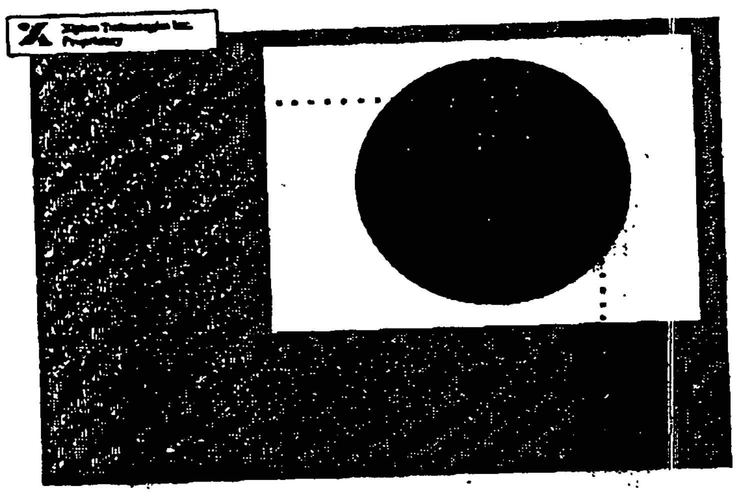


Figure 5. View Resulting from Independent Camera Motion

Again, the user does not experience nausea, this time because the window frame has moved to follow the video image. Parts of the scene that were visible to the operator before the camera moved are still located in the same part of his field of view. The image of the Earth and Space does not "slide" in the HMD frame; it just becomes partly grayed out.

6

3.3. Compensation for Communications Delay

The net effect of a communications delay in an HMD master-slave arrangement is the combination of the two previous effects. When the operator makes a head motion, there is initially no response from the camera. This is momentarily equivalent to the camera-fixed case. After a round-trip time delay, the images resulting from the camera's motion will be seen. This is equivalent to independent camera motion.

Compensation for time delay is thus acheived by continuously combining the window frame displacements mandated by head motion, with those indicated by the gimbal motion sensors.

Consider the final example. Figure 6 is the initial view of the Earth with operator's head and camera at rest. The operator turns his head to the left and stops. If there were *no delays* from transmission or camera motion, the instantaneous (and desired) outcome would be that of Figure 7.

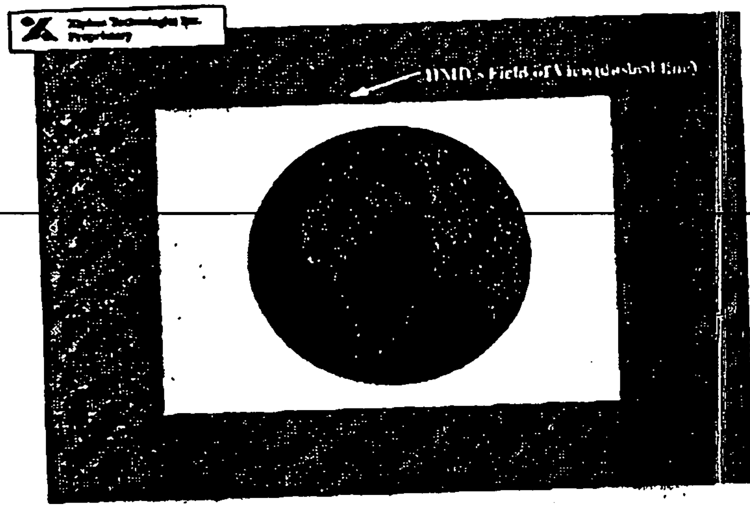


Figure 6. Initial View

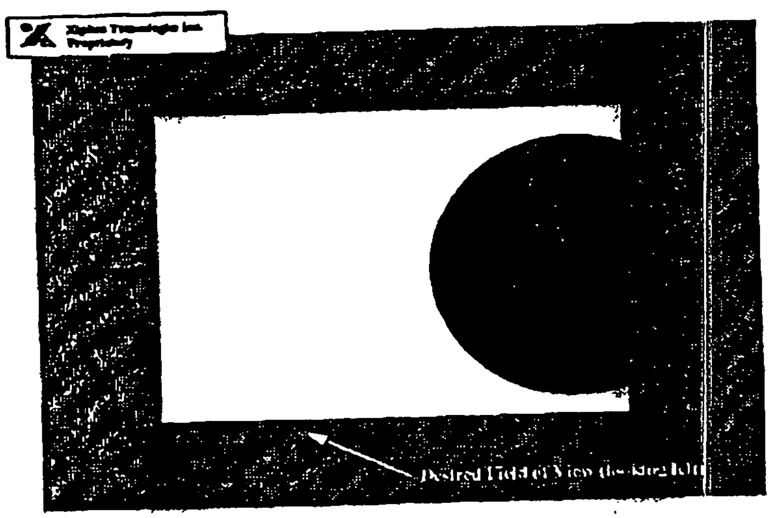
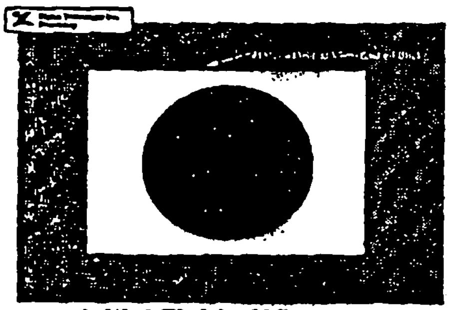
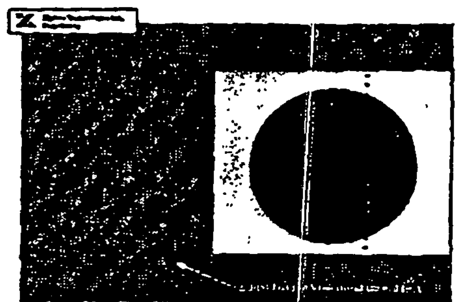


Figure 7. View to the Left

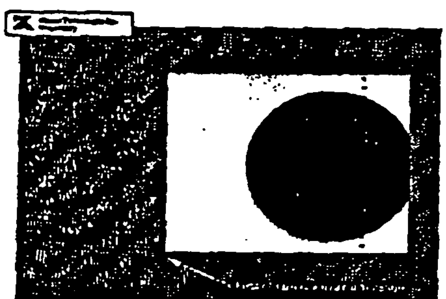
With a delayed video response, the following happens: the operator's motion to the left causes the window frame and image contents to move to the right accordingly. The operator has the sensation of looking away from the window frame. As the camera returns its delayed response, the operator has the sensation of the window frame moving, and the scene beyond the window staying still in space.



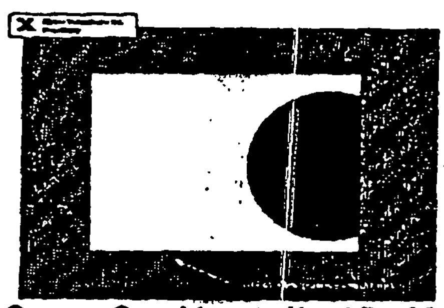
Initial Field of View



Head Turned to the Left



Head Stopped, Camera Responding (Delayed)



Camera Caught up to Head Position

Figure 7. Sequence for Time Delay Compensation

4. Summary

One limitation of the concept must be kept in mind. Events seen by the camera will always be delayed by the downlink time before being displayed in the HMD. This method does not purport to convey images faster than the speed of light, and does not use any form of image synthesis or predictive logic to generate all or part of an image which is being viewed by the camera, but has not yet been received by the operator.

A good example would be viewing a spin-stabilized satellite in geosynchronous orbit, from a camera on a nearby free-flying servicer. The rotational position of the spinning satellite viewed by the operator would lag the actual position by the downlink time. If the operator were controlling a manipulator arm on the servicer, he would see the arm move in his HMD some time after issuing the command. This time would be the combined uplink and downlink delays.

The following key points summarize the concept.

1. The view depicted *within the window frame* only moves relative to the HMD FOV when the operator's head moves. This is the key to providing a stable frame of reference.

2. The window frame moves relative to the HMD FOV in response to the camera motion, to locate the frame in 3-D space relative to the operator's head position.

3. The window frame also moves relative to the HMD FOV in response to the operator's head motion, to locate the frame and view in 3-D space relative to the operator's head position.

4. All camera and head motions are *continuously* transformed in 3-D space to provide a continuous, fluid response.

5. The method is particularly appropriate for wide fields of view (in the camera and HMD), as it will allow the operator to concentrate on the central field of view, while the gray window frame will only obscure peripheral areas temporarily.

6. The method is suitable for translations and rotations. Provided the camera is gimballed similarly to a human head, there are minimal depth-of field or parallax considerations. Wide angle distortions are transient.

7. Camera orientation can be sensed by gimbal position (on a fixed platform), or gimbal plus inertial orientation on a moving platform. Additionally, software image locking could further stablize the scene, particularly in cases where the camera is subject to motion vibration which cannot be damped by the gimbal.

H_2N-Ser-Val-Ser-Glu-Ile-Gln-Leu-Met-His-Asn-Leu-Gly-Lys-His-Leu-Asn-Ser-Met-Glu-
Arg-Val-Glu-Trp-Leu-Arg-Lys-Lys-Leu-Gln-Asp-Val-His-Asn-Phe-COOH

Fig. 1

H_2N-Ser-Val-Ser-Glu-Ile-Gln-Leu-Met-His-Asn-Leu-Gly-Lys-His-Leu-Asn-Ser-Met-Glu-
Arg-Val-Glu-Trp-Leu-Arg-Lys-Lys-Leu-Gln-Asp-Val-NH_2

Fig. 2

H_2N-Ser-Val-Ser-Glu-Ile-Gln-Leu-Met-His-Asn-Leu-Gly-Lys-His-
Leu-Asn-Ser-Met-Glu-Arg-Val-Glu-Trp-Leu-Arg-Lys-Leu-Leu-NH_2

Fig. 3

H_2N-Ser-Val-Ser-Glu-Ile-Gln-Leu-Met-His-Asn-Leu-Gly-Lys-His-Leu-Asn-Ser-Met-Glu-

Arg-Val-Glu-Trp-Leu-Arg-Lys-Leu-Leu-Gln-NH_2

Fig. 4

H_2N-Ser-Val-Ser-Glu-Ile-Gln-Leu-Met-His-Asn-Leu-Gly-Lys-His-Leu-Asn-Glu-Met-Glu-

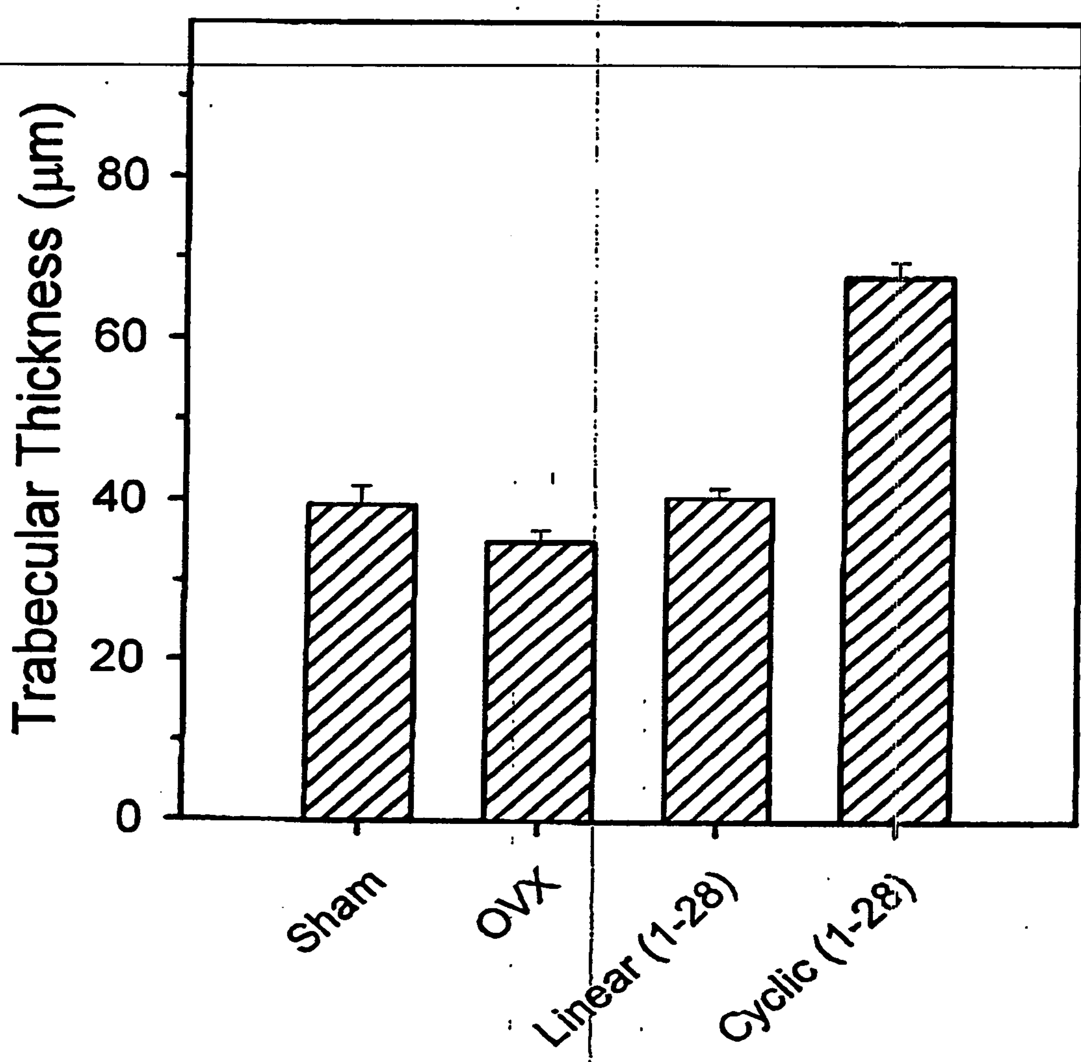
Arg-Val-Glu-Trp-Leu-Arg-Lys-Leu-Leu-Gln-Asp-Val-NH_2

Fig. 5

H_2N-Ser-Val-Ser-Glu-Ile-Gln-Leu-Met-His-Asn-Leu-Gly-Lys-His-Leu-Asn-Glu-Met-Glu-

Arg-Val-Glu-Trp-Leu-Arg-Lys-Leu-Leu-NH_2

Fig. 6



Trabecular Thickness (μm)
80
60
40
20
0
Sham
OVX
Linear (1-28)
Cyclic (1-28)

Fig. 7

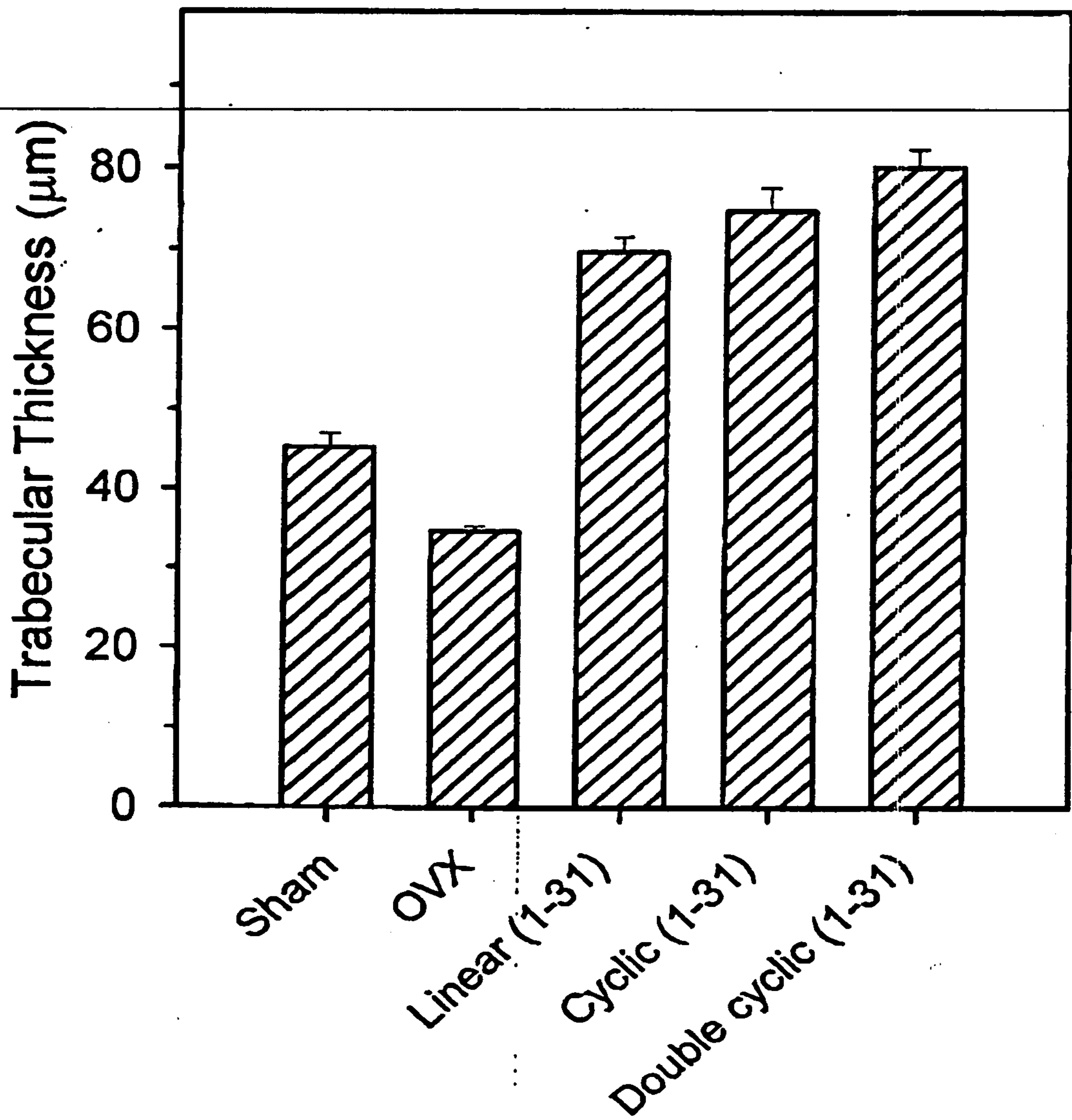

Trabecular Thickness (μm)
80
60
40
20
0
Sham
OVX
Linear (1-31)
Cyclic (1-31)
Double cyclic (1-31)

Fig. 8